CORONOARY AUTOREGULATION BASED ON OXYGEN FLOW: A MODEL OF OXYGEN SUPPLY TO CORONARY ARTERIOLAR SMOOTH MUSCLE IN INJURY AND ENDOTHELIAL DYSFUNCTION

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***Abstract* - A multi-layers theoretical model of a coronary arteriolar smooth muscle was developed to elucidate the role of oxygen in the control of coronary blood flow. Both oxygen transport by diffusion and local tissue metabolism were considereded. Oxygen partial pressure in all layers was calculated. The model sugggets that in normal conditions, oxygen partial pressure reaches its minimal value in the media, where oxygen consumption is the greatest. When the smooth muscle is injured, its metabolic demands are increased in order to heal, resulting in a P_{O_2} decline. These results are in agreement with experimental results. The model also shows that increased myocardial oxygen partial pressure causes the arteriolar smooth muscle to contract in response to lack of oxygen. Decreased myocardial oxygen pressure results in expansion of the arteriole allowing greater coronary flow.**

I. INTRODUCTION

Experimental studies show that the arterial wall is oxygenated by two sources [Fig. 1]. The inner layer of the arteriolar smooth muscle receives oxygen directly from the vessel lumen, whereas the rest of the surrounding tissue is supplied by the vasa vasorum [1, 2,3]. The primary mechanism of oxygen supply is diffusion [3].

Previous theoretical models of oxygen supply to the arteriolar smooth muscle focused on O_2 and CO_2 transport between arterioles and surrounding tissue. However, no model accounts for both mass-transport through the inner layers of the arteriole and the supply by the vasa vasorum of the outer vessel layer. Furthermore, such a model was not specifically applied to the coronary bed.

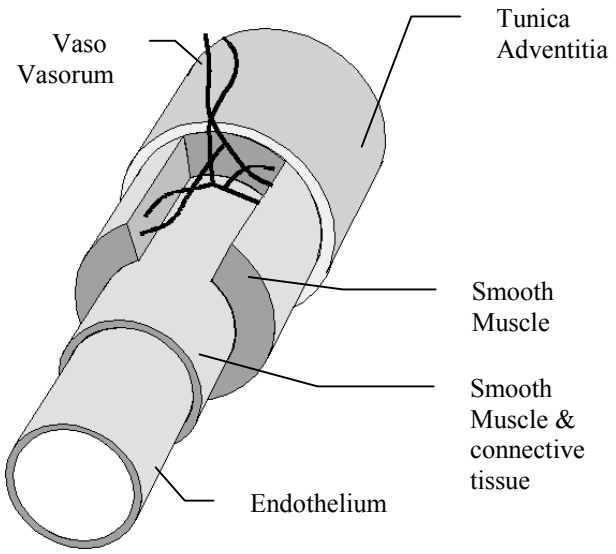

Fig. 1. Schematic diagram of the arteriole wall layers

In the study presented here, a model of O_2 supply to a coronary arteriolar smooth muscle was developed to calculate oxygen partial pressure in all layers of the arteriole wall in various states. Both oxygen transport by diffusion and local tissue metabolism were incorporated. Oxygen partial pressure in all layers was calculated.

II. METHODS

A theoretical model of O_2 supply to a coronary arteriolar smooth muscle was developed. The model consists of five cylindrical layers: a blood vessel lumen, an intima, a medial smooth muscle, an adventitial segment consisting of connective tissue component and a surrounding tissue. Experiments show that axial oxygen diffusion is very small in the perfused tissue along the arteriole [4]. Therefore, diffusion in the axial direction was neglected assuming it has only minor

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effect in comparison with radial oxygen diffusion. Both oxygen transport by diffusion and local tissue metabolism were considered.

Fig. 2 shows the basic structure of the three inner segments of the model and a sketch of the oxygen tension drop along the radial direction in two different metabolic states. The inner radius of the vessel is designated as R_i and the outer radius of the Intima as R_o. Oxygen partial pressure in the Intima and in the smooth muscle are designated as *PIn* and *Ps*, respectively.

Experimental observations show that oxygen unloading of erythrocytes during their motion along coronary arterioles is insignificant to the myocardial supply [5]. Also, Mean intra-myocardial partial pressure of varies in a small range and is determined by the interaction of different capillary diffusion fields [6, 7]. Thus, boundary conditions include oxygen partial pressure inside the inner layer that is equal to that in the blood, and at a distance away from the vessel partial pressure equals to the mean intramyocardial oxygen tension that is determined by capillary oxygen supply and myocardial consumption. Furthermore, partial pressures for the different layers had to match at the blood-smooth muscle wall, wall-adventitia, and adventitia-tissue boundaries. Also flow leaving one layer must be equal to the flow entering the next layer.

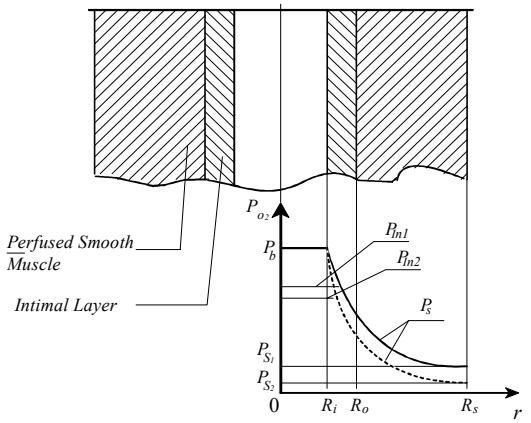

Fig. 2: A model of the arteriolar smooth muscle Oxygen distribution

The model was run in various states to study its behavior in normal and abnormal conditions. The sensitivity of oxygen availability in the smooth muscle to changes in intramyocardial pressure and in arterial blood P_{O_2} were examined.

III. RESULTS

Fig. 3 shows oxygen partial pressure drop as a function of the distance from the center line of the arteriolar lumen under normal conditions. The pressure reaches its minimum in the media-adventitia boundary. Then it increases until it reaches mean intramyocardial tension. This behavior exhibited by the model is similar to that found in experimental studies [8].

Fig. 4 shows oxygen partial pressure drop when the smooth muscle is damaged. In the particular example shown here metablic demands were doubled in the smooth muscle layer to compensate for healing processes. This situation results in a P_{O_2} decline in comparison to partial pressure deviation under normal conditions.

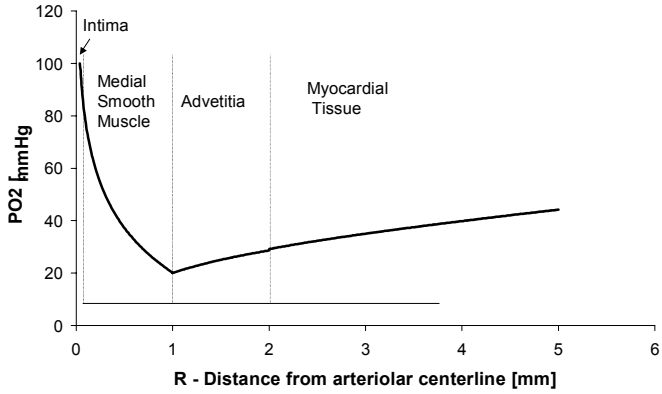

Fig 3. Oxygen partial pressure drop as a function of the distance from the center line of the arteriolar lumen

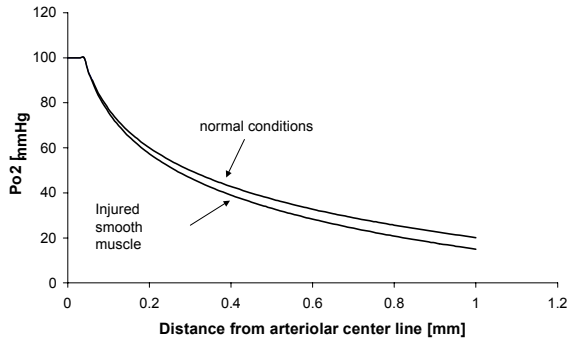

Fig. 4: Oxygen partial pressure drop for the Intima and the smooth muscle sections for healthy and injured still healing smooth muscle

IV. DISCUSSION

The model shows that in normal conditions, oxygen partial pressure reaches its minimal value in the media, where oxygen consumption is the greatest. Then partial pressure gradually increases until it reaches mean intramyocardial tension. When the smooth muscle is injured, its metabolic demands are increased in order to heal, resulting in a P_{O_2} decline. When the intimal endothelium is injured, less oxygen passes to the inner parts of the smooth muscle, hence leading to lower values of P_{O_2} at the media. These results are in agreement with experimental data obtained from peripheral arterioles in animals.

This model of arteriolar smooth muscle contraction as a function of oxygen availability was developed to be integrated into a comprehensive model of the coronary bed and a model of the heart to study cardiac autoregulatory mechanisms.

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